Numerical Weather Prediction

Developments in the correction of radiosonde relative humidity biases

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DEVELOPMENTS IN THE CORRECTION OF

RADIOSONDE RELATIVE HUMIDITY BIASES

by

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Summary

Currently, the Observation Processing System adjusts radiosonde relative humidity observations before assimilation into the NWP models, since using unadjusted values can result in spurious depletion of analysed cloud cover. The current adjustment scheme is a statistically derived bias relationship applied as a function of observed value, adding moisture to observations that are close to saturation. Fundamentally, this method relies on a relationship between relative humidity and cloud cover, as defined by the model cloud scheme. It uses cloud cover estimates derived from relative humidity profiles to make comparisons with surface reports of cloud, which then allows humidity adjustments to be calculated. Real time adjustments are desirable because their design can make them robust to future changes in measuring equipment and model physics, whereas the statistical scheme requires repeated re-derivation in order to account for these things. This paper describes such a scheme, based on the current statistical approach, in detail and presents the results of tests using the mesoscale version of the Unified Model. The test results showed a slightly negative overall forecast impact. Further investigation and tuning of the scheme is planned, with the hope of including it in a future Observation Processing System upgrade having obtained positive forecast impacts.

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1. Introduction

Assimilation of radiosonde relative humidity (rh) data directly into the Met Office operational forecast models can result in spurious depletion of analysed cloud cover. A number of factors contribute to this effect. Instruments from the various radiosonde manufacturers show different degrees of dry bias near saturation and this can vary by batch and pre-launch storage conditions. Model vertical resolution and the method chosen to interpolate from reported levels to model levels affect the representation of thin cloud sheets in the analysis. Another potential source of error is the overlap assumption used by the model to derive total cloud cover from a profile of cloud fractions on model layers.

Radiosonde rh measurements are, therefore, bias corrected by the Observation Processing System (OPS), before assimilation. The current operational scheme for this, derived in 1994, is a statistically based adjustment. Recently, the focus has been on developing a real-time scheme to individually assess and adjust the bias of each radiosonde ascent. (See Sharpe & Macpherson 2001 for a preliminary account of this work.)

In essence, the adjustment scheme compares surface reports of cloud cover with the total cloud implied by the radiosonde, which is calculated using the model cloud scheme relationship between rh and cloud, followed by an overlap assumption. Section 2 of this report outlines the methods of deriving both the statistical and real-time adjustments from this comparison. Since the modelled rh-cloud relationship is not constant for ice cloud, part of the real-time scheme is an attempt to 'calibrate' this relationship using a local assessment of the model background field.

Section 3 of this report describes the testing and tuning of the real-time scheme using assimilation and forecast experiments. The primary focus in this work was on verification of cloud amount, screen temperature, precipitation and visibility.

2. Scheme outlines

2.1 Statistical Correction

Lorenc et al. (1996) describe this scheme in a paper that also presents an example of the depletion of analysed cloud cover due to assimilating radiosonde rh data. To derive the correction, the rh-cloud relationship (see Figure 1) applied in the Unified Model (UM) is used to obtain implied cloud profiles for a large sample of radiosonde ascents whose rh data have been interpolated to model levels. The relationship used and its inverse are described in detail in Appendices B and C respectively. The maximum random overlap assumption is then used to diagnose a total cloud fraction, C_{sonde}, for each of profile. Taking collocated synop reports of total cloud cover C_{obs}, and using Equation 1 gives a mean correction for the rh(C_{sonde}) value corresponding to each rh(C_{obs}). A piece-wise linear fit to these data points is then used to define the rh correction (as shown in Figure 2).

Equation 1: $$\Delta rh = rh(C_{obs}) - rh(C_{sonde})$$

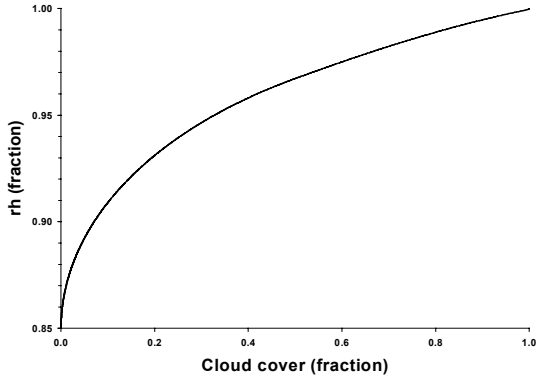

Figure 1: Relative humidity-cloud relationship in the Unified Model

Initially, this method used all radiosonde reports passing quality control in a given period, to derive a generalised adjustment for all radiosondes. It has since been used to derive corrections specific to each radiosonde instrument. This process identified corrections for six groups of instruments that showed similar biases over a one-year period. The corresponding graphs are broadly similar to Figure 2 but have maximum adjustments ranging from 1 to 7%. When processed onto the 38 levels of the mesoscale model, VIZ radiosondes were judged to require no adjustment.

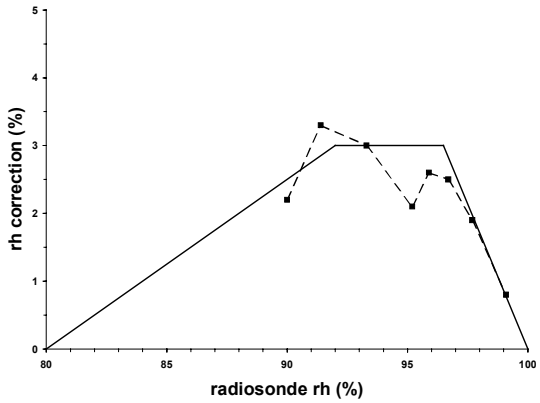

Figure 2: Statistically derived relative humidity correction

2.2 Real-time Correction

Various factors point to the need to correct radiosonde rh measurements in real-time. Statistical corrections need revision following the introduction of new or modified instruments, model resolution and physics schemes. The difference in bias characteristics across batches of instruments or with various storage procedures also has an impact on the effectiveness of a statistical scheme. In addition, the possible dependence of rh bias on synoptic conditions makes a real-time correction attractive. The alternative would be an unwieldy implementation of statistical correction sets applied according to a real-time assessment of the prevailing synoptic situation.

The real-time correction is a development of the statistical scheme, using the UM rh-cloud relationship to derive the cloud profiles implied from each radiosonde ascent that has a collocated synop cloud report. (The statistical scheme is applied by default for those ascents with no synop cloud data to compare against.) All levels (i) of the implied cloud profiles are then iteratively scaled using Equation 2 such that the total cloud fraction diagnosed from a maximum random overlap assumption is within a fixed tolerance of C_{obs} for each ascent. In cases where C_{obs} = 1, a single scaling is performed to ensure that complete cover is implied from the rh profile. The corrected rh values are then obtained from the scaled cloud profiles by the inverse of the UM rh-cloud relationship. Since we attempt to correct only for effects giving rise to a dry bias, the scheme only permits positive rh adjustments.

Equation 2: $$C_{sonde}^{n+1} = MaxRandom\left\{ C_i^n \frac{C_{obs}}{C_{sonde}^n} \right\}$$

One tuneable parameter in the scheme is the tolerance to which the implied cloud profiles match the synop cloud reports. This should be small compared with a typical mean bias in the analysis; ≈ -0.5 octas in the case of the mesoscale configuration of the UM. Currently a value of 0.1 octas is set.

Two complexities of the model cloud physics call for a modification to the simple use of the rh-cloud curve in Figure 1. The rh-cloud relationship applies only to layer cloud, and convective cloud may be present in the model background. Secondly, the relationship applies exactly in the model only for liquid cloud. For ice cloud, it is only an equilibrium condition and the amount of ice cloud may differ from that implied from the rh according to whether the cloud is growing or decaying.

Our approach to this complexity is to include a 'calibration' of the rh-cloud relationship based on the difference between the total cloud cover in the model background field (C_{BG}) and that implied by the background rh profile (C_{BG_rh}). This leads to Equation 3 where we redefine the target for the scaling algorithm, and replace C_{obs} by C_{target} in the iterative scaling in Equation 2 and the tolerance test which follows it.

Equation 3: $$C_{target} = C_{obs} - (C_{BG} - C_{BG_rh})$$

This formulation has the advantage of allowing automatically for any future changes to the model physics without modifying the scheme for sonde rh adjustment.

While all departures from Figure 1 which affect total cloud cover in the model can be swept into Equation 3, the specific example of the presence of convective cloud is more naturally handled through the overlap assumption. The model total cloud cover C_{BG} is obtained by combining the layer cloud and convective cloud fractions at each level of the profile before applying the overlap assumption. So, if we use this approach in deriving C_{sonde}, and if the model background convective cloud is a realistic indicator of observed convective cloud, then we account (at least partially) for one source of discrepancy between C_{sonde} and C_{obs} before any rh correction is estimated. For

consistency we calculate C_{BG_rh} in the same way and so restrict the 'calibration' of Equation 3 to compensating for the effects of ice cloud.

The scheme relies on both observed rh profiles that imply non-zero cloud fractions and the availability of synop cloud data for the majority of radiosonde locations. It cannot correct unusually dry ascents and will revert to the statistical form in the absence of the required synop data.

2.3 Application of real-time scheme

The table below shows the logic applied in order to implement the real-time adjustment scheme described in section 2.2. A second tunable parameter in the scheme as shown here is the threshold for observed cloud below which we do not attempt any rh adjustment. This option is available primarily to allow the scheme to be consistent with Nimrod processing but in our trials, all non-zero synop cloud covers are used to derive a profile scaling. (Nimrod is the system used to provide cloud data for assimilation via the Moisture Observation Pre-processing System (MOPS). See Golding 1998, Macpherson et al. 1996 & Macpherson et al. 2002 section 4.3 for more details of these two systems.)

<table>
<tr><td colspan="2">$C_{sonde} > 0$</td><td>$C_{sonde} = 0$</td></tr>
<tr><td colspan="2">Collocated synop report</td><td>No collocated synop report</td><td rowspan="3">Do not correct</td></tr>
<tr><td>C_{obs} > threshold</td><td>C_{obs} < threshold</td><td rowspan="2">Apply statistical correction</td></tr>
<tr><td>Apply profile scaling</td><td>Do not correct</td></tr>
</table>

Appendix A details the equations and logic applied in the real-time adjustment code. The code is not identical with this schematic but the logic outcomes are the same.

3. Trials

Mesoscale model runs out to T+36 over for a 2-day assimilation period in January 2000 allowed preliminary tests of the scheme. This period had shown sensitivity to radiosonde rh data in data impact experiments (Macpherson 2002, section 4.2). The tests enabled a tuning process to take place. Following this, subsequent trials used a cloud tolerance of 0.1 octa, background convective cloud included in the overlap calculation, zero minimum observed cloud threshold and the local 'calibration' accounting for the model's prognostic ice scheme.

The main trials used were, using the mesoscale configuration:

- 10-day rerun from January 2000
- 12 cases studies chosen from a variety of synoptic conditions
- real-time parallel trial from April 20th to June 14th 2001
- a rerun of the whole of May 2001

The real-time parallel trial and case studies both showed that the real-time approach gave a slight performance detriment for all key variables, especially in the UK: ETS for total cloud amount forecasts deteriorated by between 0.02 and 0.04. Figure 3 shows a typical plot, taken from the real-time trial, indicating that cloud cover spin-up is slightly worsened by using the real-time scheme. Conversely, the signal from the 10-day test for January 2000 was slightly positive. The magnitudes of the performance changes in all three trials are, however, essentially negligible.

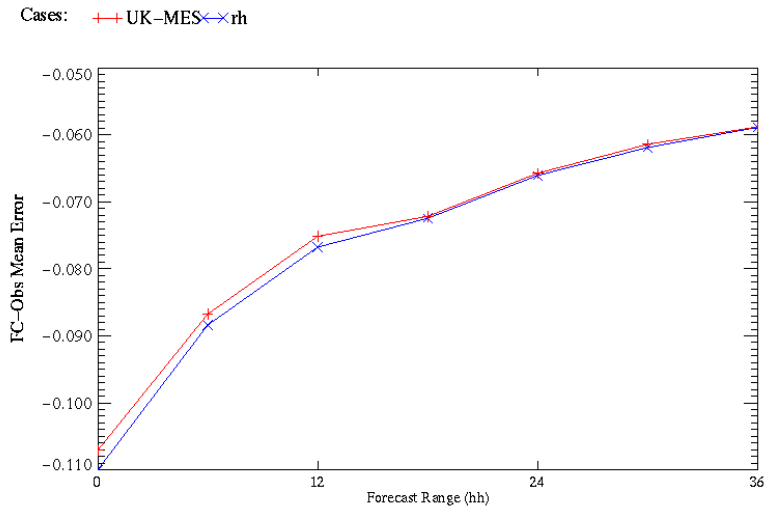

Figure 3: Mean cloud fraction forecast-observation differences

In detail:

- Forecast statistics for the case studies showed a small negative impact on screen level temperature (by up to 0.23% of the initial rms error) and total cloud cover (0.02 ETS detriment) but a very small positive impact for visibility and precipitation. Overall, impact was slightly positive. Limiting the statistics to verification over the UK only, most were similar but negative impacts on visibility and precipitation resulted in a slightly negative impact.
- The real-time parallel trial gave more coherent results. The overall impact was very slightly negative (0.3% of the total weighted score for UK stations). Screen temperature at t+6 was 0.6% worse and the average ETS for total cloud cover was reduced from 0.221 to 0.217. Rms cloud cover errors were slightly increased.

The rerun of May 2001 was used to gain insight into the performance of the scaling algorithm, rather than forecast impact. Figure 4 shows the initial cloud differences plotted against the residual differences, following adjustment, for both the statistical and real-time schemes. ("Difference" being the radiosonde total implied cloud fraction minus the synop total cloud report.) There are two adjustment regimes in the real-time scheme evident in this figure:

- In cases of initial negative difference, the real-time scheme gives better compensation for large errors. The degree of scatter in the residual differences is smaller and the residual bias reduced.
- In cases of initial positive difference, the real-time scheme gives less enhancement of this difference and a reduction in the residual bias.

Overall, the real-time scheme gives an almost unchanged cloud fraction bias as implied from the processed observations relative to the synop reports, increasing it from -0.018 with the statistical adjustment to -0.024: the rms difference reduces from 0.12 to 0.08. Both the statistical and real-time schemes can neither respond where sonde implies zero cloud or give a negative adjustment where the sonde implies more cloud than the synop. Thus, adjusted points from the real-time scheme cluster around residual differences that are either equal to the initial error or zero.

Mesoscale model runs to date have shown that approximately 30% of radiosonde ascents in the model domain do not have collocated synop reports. This apparently high figure requires further investigation but is due in part to autosondes having no accompanying manual observation of total cloud cover. If autosondes make up a significant fraction of the radiosonde network it may become necessary change the real-time scheme, substituting synop cloud reports for MOPS total cloud cover data, prepared from Nimrod products.

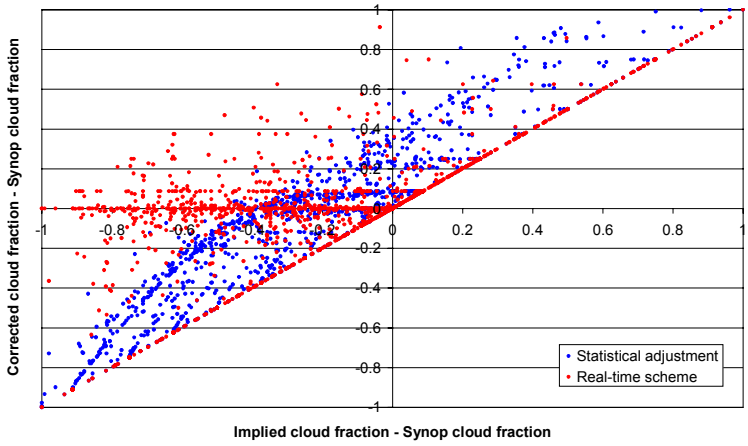

Figure 4: Initial and residual cloud fraction differences from synop reports

4. Conclusions

Trial results suggest that the performance of the real-time radiosonde rh adjustment is broadly similar to that of the previous statistical scheme. It improves comparisons between synop reports of total cloud and the cloud cover implied by applying the model rh-cloud relationship and overlap assumption to radiosonde rh profiles. Forecast experiments show an overall neutral or slightly negative impact from changing from the statistical to real-time schemes. This signal is present when considering cloud amount, screen temperature, precipitation and visibility.

Although the real-time scheme does not show an improvement over the statistical adjustment, the formulation is preferable, as it does not need re-derivation following changes to model physics or instrument technology and performance. However, for ascents with no collocated synop report, the scheme still requires a statistical default. Improvement to the robustness of the statistical default to changes in models or instrumentation is possible by adding code to update the statistics automatically using a history of real-time time corrections.

Further investigation and tuning of the real-time scheme is planned, with the hope of including it in a future Observation Processing System upgrade having obtained positive forecast impacts. This work may include using MOPS total cloud data as an alternative to requiring a statistical default adjustment; an important change if the network of autosondes continues to grow. Future work will also need to consider treating radiosonde rh profiles whose initial implied total cloud cover is zero, as both the current statistical and real-time adjustments can only be applied where this is not the case.

5. References

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Appendix A: Profile scaling algorithm

define diagnostic relationship between cloud and rh $C = f(rh)$

define maximum random overlap algorithm $C_{total} = TOT\{C_i\}$

where i denotes model levels

interpolate sonde rh observations onto model levels $\left\{rh_i^{sonde}\right\}$

background rh profile $\left\{rh_i^{bg}\right\}$

background convective cloud profile $\left\{C_i^{bg_convective}\right\}$

if accounting explicitly for convective cloud:

derive total cloud implied by sonde $C_{total}^{sonde} = TOT\left\{f\left(rh_i^{sonde}\right)+C_i^{bg_convective}\right\}$

derive total cloud implied by background rh $C_{total}^{bg_implied} = TOT\left\{f\left(rh_i^{bg}\right)+C_i^{bg_convective}\right\}$

background convective cloud fraction $C_{convective}^{bg} = TOT\left\{C_i^{bg_convective}\right\}$

else:

derive total cloud implied by sonde $C_{total}^{sonde} = TOT\left\{C_i^{sonde}\right\}$

derive total cloud implied by background rh $C_{total}^{bg_implied} = TOT\left\{f\left(rh_i^{bg}\right)\right\}$

background convective cloud fraction $C^{bg_convective} = 0$

background convective cloud $\left\{C_i^{bg_convective}\right\} = \{0\}$

collocated SYNOP cloud report C_{total}^{synop}

background total cloud C_{total}^{bg}

if not applying 'calibration' for ice cloud:

$C_{total}^{bg_implied} = C_{total}^{bg}$

if C_{total}^{synop} is available:

if $C_{total}^{sonde} > C^{bg_convective}$:

if C_{total}^{synop} > minimum observed cloud threshold:

if $C_{total}^{synop} - \left(C_{total}^{bg} - C_{total}^{bg_implied} \right) > C_{total}^{sonde}$ AND $0 \le C_{total}^{synop} - \left(C_{total}^{bg} - C_{total}^{bg_implied} \right) < 1$:

while $\left| C_{total}^{synop} - \left(C_{total}^{n} + \left(C_{total}^{bg} - C_{total}^{bg_implied} \right) \right) \right| >$ tolerance :

where $C_{total}^{0} = C_{total}^{sonde}$:

if $MAX\left\{ C_i^n \dfrac{C_{total}^{synop}}{C_{total}^{n} + \left(C_{total}^{bg} - C_{total}^{bg_implied} \right)} \right\} > 1$:

$$C_{total}^{n+1} = TOT\left\{ C_i^n \frac{\left(C_{total}^{synop} - \left(C_{total}^{bg} - C_{total}^{bg_implied} \right) \right)}{C_{total}^{n}} + C_i^{bg_convective} \right\}$$

else if $C_{total}^{n} + \left(C_{total}^{bg} - C_{total}^{bg_implied} \right) \le 0$:

$$C_{total}^{n+1} = TOT\left\{ C_i^n \frac{\left(C_{total}^{synop} - \left(C_{total}^{bg} - C_{total}^{bg_implied} \right) \right)}{C_{total}^{n}} + C_i^{bg_convective} \right\}$$

else:

$$C_{total}^{n+1} = TOT\left\{ C_i^n \frac{C_{total}^{synop}}{C_{total}^{n} + \left(C_{total}^{bg} - C_{total}^{bg_implied} \right)} + C_i^{bg_convective} \right\}$$

else if $C_{total}^{synop} - \left(C_{total}^{bg} - C_{total}^{bg_implied} \right) \ge 1$:

$$\left\{ C_i^n \right\} = \left\{ C_i^{sonde} \right\} \left(MAX\left\{ C_i^{sonde} \right\} \right)^{-1}$$

else :

do not correct

derive corrected rh profile $\left\{ rh_i^{corrected} \right\} = \left\{ f^{-1}\left(C_i^n \right) \right\}$

else:

do not correct

else:

do not correct

else:

apply statistical correction as in the current OPS

Appendix B: Conversion from relative humidity to cloud fraction

See Smith et al. 1999 and Cusack 2000

$$C'(rh) = \begin{cases} 4\cos^2\left(\frac{1}{3}\left[\pi + \cos^{-1}\left(\frac{3}{2^{3/2}}\left[\frac{rh - rh_{ci}}{1 - rh_{ci}}\right]\right)\right]\right) & \text{for } rh_{ci} \le rh \le \frac{5 + rh_{ci}}{6} \\ 1 - \left(\frac{3}{2^{1/2}}\left[\frac{1 - rh}{1 - rh_{ci}}\right]\right)^{2/3} & \text{for } \frac{5 + rh_{ci}}{6} \le rh \le 1 \\ 1 & \text{for } 1 \le rh \end{cases}$$

where rh_{ci} is the critical rh at model level i

$$Q'_N = \begin{cases} \sqrt{2C'(rh)} - 1 & \text{for } C'(rh) \le 0.5 \\ 1 - \sqrt{2\left[1 - C'(rh)\right]} & \text{for } C'(rh) > 0.5 \end{cases}$$

$$Q_N = \frac{Q'_N + K_2}{K_1}$$

$$\text{where } K_1 = \begin{cases} 0.816 & \text{for i} \le B \\ 0.9045 & \text{for i} > B \end{cases}$$

$$K_2 = \begin{cases} 0.184 & \text{for i} \le B \\ 0.0955 & \text{for i} > B \end{cases}$$

where B denotes the number of levels in model boundary layer

$$C(rh) = \begin{cases} 0 & \text{for } Q_N \le -1 \\ 0.5(1 + Q_N)^2 & \text{for } -1 < Q_N \le 0 \\ 1 - 0.5(1 - Q_N)^2 & \text{for } 1 > Q_N > 0 \\ 1 & \text{for } Q_N \ge 1 \end{cases}$$

Appendix C: Conversion from cloud fraction to relative humidity

$$Q_N = \begin{cases} \sqrt{2C} - 1 & \text{for } C \le 0.5 \\ 1 - \sqrt{2(1-C)} & \text{for } C > 0.5 \end{cases}$$

$$Q'_N = Q_N K_1 - K_2$$

where $K_1 = \begin{cases} 0.816 & \text{for } i \le B \\ 0.9045 & \text{for } i > B \end{cases}$

$$K_2 = \begin{cases} 0.184 & \text{for i} \le B \\ 0.0955 & \text{for i} > B \end{cases}$$

where i denotes model level

where B denotes the number of levels in model boundary layer

$$C' = \begin{cases} \frac{1}{2}\left(Q'_N + 1\right)^2 & \text{for } Q'_N \le 0 \\ 1 - \frac{1}{2}\left(1 - Q'_N\right)^2 & \text{for } Q'_N > 0 \end{cases}$$

$$rh(C') = \begin{cases} \frac{2^{3/2}\left(1 - rh_{ci}\right)}{3} \cos\left(3\cos^{-1}\sqrt{\frac{C'}{4}} - \pi\right) + rh_{ci} & \text{for } C' \le 0.5 \\ 1 - \frac{2^{1/2}\left(1 - rh_{ci}\right)}{3}\left(1 - C'\right)^{3/2} & \text{for } C' > 0.5 \end{cases}$$